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Tiling Patterns and the Mechanical Properties of Topologically Interlocked Materials

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Topologically interlocked materials (TIMs) are material systems consisting of one or more repeating unit blocks assembled in a planar configuration such that each block is fully constrained geometrically by its neighbours. The assembly is terminated by a frame that constrains the outermost blocks. The resulting plate-like structure does not use any type of adhesive or fastener between blocks but is capable of carrying transverse loads. These material systems are advantageous due to their potential attractive combination of strength, toughness, and damage tolerance as compared to monolithic plates, especially when using lower strength materials. TIMs are damage tolerant due to the fact that cracks in any single block cannot propagate to neighbouring blocks. Many configurations of TIMs have been conceptualized in the past, particularly in architecture, but less work has been done to understand the mechanics of such varied assembly architectures. This work seeks to expand our knowledge of how TIM architecture is related to TIM mechanics.

The present study considers TIMs created from the Archimedean and Laves tessellations. Each tessellation is configured as a TIM by projecting each edge of a tile at alternating angles from the normal to the tiling plane. For each tiling, multiple symmetries exist depending on where the frame is placed relative to the tiling. Six unique tilings and their multiple symmetries and load directions were considered, resulting in 19 unique TIM configurations.

All TIM configurations were realized with identical equivalent overall assembly dimensions. The radius of the inscribed circle of the square and hexagon frames were the same, as well as the thickness of the assemblies. The tilings were scaled to possess the similar same number of building blocks within the frame. Finite element models were created for each configuration and subjected to two load types under quasi-static conditions: a prescribed displacement applied at the center of the assembly, and by a gravity load.

The force deflection response of all TIM structures was found to be similar to that of a Mises truss, comprised of an initial positive stiffness followed by a period of negative stiffness until failure of the assembly. This response is indeed related to the internal working of load transfer in TIMs. Owing to the granular type character of the TIM assembly, the stress distribution follows a force-network. The key findings of this study are:

- The load transfer in TIMs follows from force networks and the geometry of the force network is associated with the dual tessellation of the respective TIM system.
- In TIMs based on Laves tessellations (centered around a vertex of the tiling rather than the center of a tile), displayed chirality and exerted a moment normal to the tile plane as they were loaded.
- TIMs resulting from tessellations with more than one unique tile, such as squares and octagons, are asymmetric along the normal to the tile plane causing a dependence of the load response to the direction of the transverse load.

Work is underway to transform these findings into general rules allowing for a predictive relationship between material architecture and mechanical response of TIM systems.

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